UNCLASSIFIED

Defense Technical Information Center Compilation Part Notice

ADP012810

TITLE: Electric Field Dependent Dimensionality of Excitonic States in Single Quantum Well Structures with Asymmetric Barriers

DISTRIBUTION: Approved for public release, distribution unlimited
Availability: Hard copy only.

This paper is part of the following report:

TITLE: Nanostructures: Physics and Technology International Symposium [6th] held in St. Petersburg, Russia on June 22-26, 1998 Proceedings

To order the complete compilation report, use: ADA406591

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, etc. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP012712 thru ADP012852

UNCLASSIFIED

Ioffe Institute
6th Int. Symp. "Nanostructures: Physics and Technology"
St Petersburg, Russia, June 22–26, 1998. **EN.04**

Electric field dependent dimensionality of excitonic states in single quantum well structures with asymmetric barriers

Yu. A. Aleshchenko, I. P. Kazakov, V. V. Kapaev, Yu. V. Kopaev and A. E. Tyurin
P. N. Lebedev Physics Institute of RAS, 117924 Moscow, Russia

Abstract. 2D–3D transformation of excitonic states dimensionality with an external electric field parallel to the growth axis has been observed in GaAs/$Al_xGa_{1-x}As$ single quantum well (QW) structures with asymmetric barriers. When the maximum of electronic wavefunction shifts to the lower barrier with field, the exciton binding energy starts to decrease. With further increase of field the transformation of 2D exciton to the quasi-3D exciton takes place. The latter involves a heavy hole in QW and an electron of resonant above-barrier state.

Introduction

The dispersion law $E(k)$ for single QW structure with asymmetric barriers has been theoretically studied in our previous paper [1]. It was shown that the localized state of electron exists only within the limited region of wave-vectors $(0, k_c)$ in the layer plane. At $k = k_c$ 2D–3D transformation of electronic states dimensionality takes place and it is possible to control k_c value and consequently the dimensionality of states by electric field.

In this paper the experimental confirmation of this effect is obtained by photoluminescence (PL) spectroscopy.

1 Samples and experimental procedure

Undoped QW of $d = 10$, 4 or 3 nm width inserted between top $Al_{0.4}Ga_{0.6}As$ and bottom $Al_{0.06}Ga_{0.94}As$ barriers of 10 and 30 nm width, respectively, were grown by MBE on semiinsulating GaAs substrates with 250 nm thick GaAs buffer layer. The QW widths were chosen so that in the former two cases ($d = 10$, 4 nm) the electron confined state in the well existed without external electric field while in the structure with 3 nm QW the electron state was no longer confined. One should expect in the latter case the 2D–3D dimensionality transformation of electronic state and corresponding exciton. The possibility to apply the electric field to the structure was provided by insertion of n^+GaAs:Si layer of 50 nm in thickness after the buffer layer as a bottom electrode and by doping of top GaAs layer with Si impurity. The active layers of the structure were inserted between top and bottom $n^+Al_xGa_{1-x}As$:Si spacers with x, thickness and doping level of 0.4, 30 nm, 6.5×10^{17} cm^{-3} and 0.06, 25 nm, $(3–6)\times10^{16}$ cm^{-3}, correspondingly. The doping levels of spacers were choosen to satisfy the flat band conditions without external electric field.

The PL spectra were excited at 80 K by 488 nm line of Ar^+ laser with the power density on the sample lower than 40 W/cm^2. The spectra were analyzed by 0.82 m double grating spectrometer and detected by photomultiplier in photon counting mode.

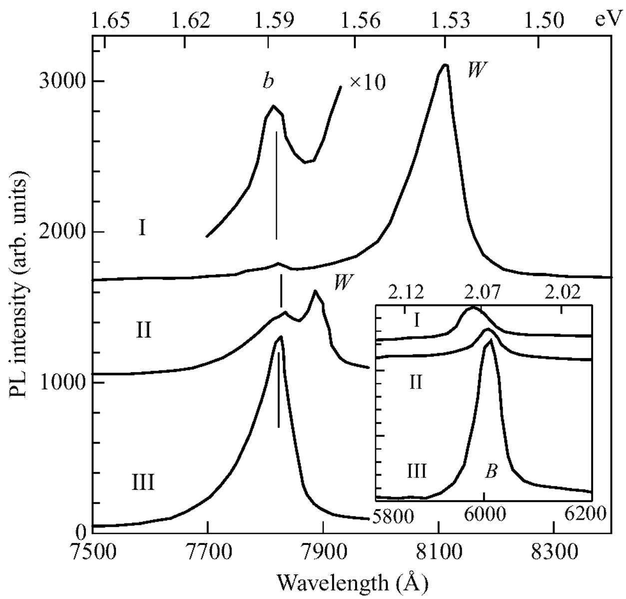

Fig 1. PL spectra of structures with $d = 10$ (I), 4 (II) and 3 (III) nm. The shortwavelength parts of respective spectra are shown in the inset.

2 Experimental results

The PL spectra of the structures with $d = 10$, 4 and 3 nm are shown in Fig. 1. The common features in the photoluminescence spectra of these structures near 1.585 and 2.07 eV are due to the contributions of lower and higher barriers respectively. Besides these features an intense peak of excitonic transition between the first space-quantized sublevels of heavy hole valence and conduction bands appears in the spectrum of the structure with 10 nm QW. Upon narrowing QW width down to 4 nm this peak loosens its intensity, broadens and shifts to the peak of lower barrier since the electron sublevel appears to be near the QW edge from the side of lower barrier. As for the structure with $d = 3$ nm the excitonic peak of QW is not detected and the corresponding 2D electron state doesn't exist.

In order to trace the excitonic state evolution with monotonous variation of lower barrier height a semitransparent top metallic electrode was evaporated on the sample with $d = 4$ nm and the contacts were prepared to it and to the n^+ buffer layer. As the negative voltage is applied to the top electrode the height of lower barrier decreases and the electronic state moves to the top of the barrier. The peak of corresponding 2D exciton in its turn moves to lower energies (curve W in Fig. 2) with the decrease of applied voltage. According to our calculations 2D electron state must dies out in fields corresponding to the voltage of -0.5 V, but excitonic peak under discussion still persists in the spectra. The point is that along with the shallowing of QW for electron the well becomes deeper for hole and hole localization increases with field. The Coulomb field of such hole localizes the electron and leads to the increase of effective depth of QW for the latter by few eV. This effect however can't explain the retention of excitonic state at

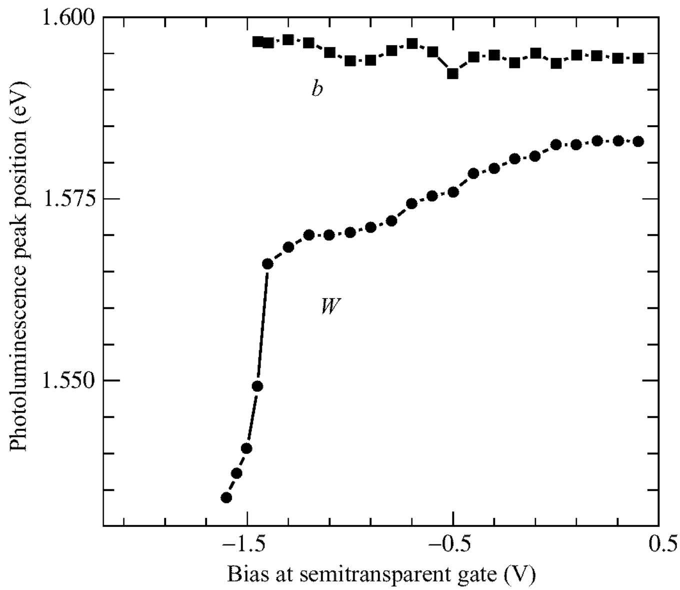

Fig 2. Experimental biass dependences of excitonic peak positions for lower barrier (b) and QW (W).

voltages lower than -0.6 V. In the voltage range of $-0.6 \div -1.4$ V the biass dependence of exciton peak energy becomes flat. This dependence steepens after -1.4 V which is inherent for indirect transitions. The electric field breaks QW exciton in the region of -1.6 V while the 3D exciton of lower barrier is ruptured earlier at the voltage of -1.45 V (curve b).

3 Theory

For theoretical interpretation of the experimental results the Schroedinger equation for electron and hole with their Coulomb interaction was numeriaclly solved using the variational method. To take into account the above-barrier states, the model of quasi-continuous spectrum formed by the artificial infinite barriers was used (the barriers are situated well away from the QW).

The variational function was chosen as:

$$\Psi_{\mathrm{ex}}(z_h, z_e, \rho) = \sum_{m=1}^{\infty} a_m \Psi_m^e(z_e) \Psi^h(z_h) \exp(-\alpha\rho),$$

where $\Psi_m^e(z_e)$—the wave function of the m-state of electron spectrum, $\Psi^h(z_h)$—hole wave function, α—variational paramenter. Using this function allows one to take into account the hole Coulomb effect on the electron spectrum. The calculations show that the localized states of the electron and the hole are bound in 2D-exciton with the binding energy of ~ 8 meV without external field. With the decrease of the voltage applied to the structure the exciton binding energy is reduced.

Approximately at $U_c = -0.6$ V the electron state localized in the well rises above lower barrier top and the exciton becomes indirect quasi-3D couple. The transitions

from the H1 hole state occure to the continuous spectrum on the electron quasi-level defined by the maximum of overlap integral between the linear combination of the electron wave functions related to the continuos spectrum and the localized heavy hole state. The behaviour of QW exciton at voltages above U_c $(-0.6 \div -1.6\ \mathrm{V})$ is consistent with the existence of electron above-barrier localized states. The latter are related to the resonances in the continuos spectrum because of reflections at the heterointerface of $Al_{0.06}Ga_{0.94}As$ and the lower contact layer of n^+GaAs.

Acknowledgements

This work has been supported in part by the Russian Foundation for Basic Research and Russian Programme "Physics of Solid State Nanostructures".

References

[1] Kapaev V. V. and Kopaev Yu. V. *JETP Lett.* **65** 202 (1997).